PNNL-13533

Russian Pulsating Mixer Pump Deployment in the Gunite and Associated Tanks at ORNL

Brian Hatchell
Ben Lewis[a]
John Randolph[a]
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March 2001

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

This work is funded by the Office of Science and Technology within the Energy's Office of Environmental Management under the Tanks Focus Area Program

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[a] Oak Ridge National Laboratory

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SUMMARY

In fiscal year (FY) 1998, Pulsating Mixer Pump (PMP) technology, consisting of a jet mixer powered by a reciprocating air supply, was selected for deployment in one of the Gunite and Associated Tanks (GAAT) at Oak Ridge National Laboratory (ORNL) to mobilize settled solids. This technology was identified during FY 1996 and FY 1997 technical exchanges between the U.S. Department of Energy (DOE) Tanks Focus Area Retrieval and Closure program, the DOE Environmental Management International Programs, and delegates from Russia as a promising technology that could be implemented in the DOE complex. During FY 1997, a prototype PMP provided by the Russian Integrated Mining Chemical Company, was tested at Pacific Northwest National Laboratory (PNNL) to observe its ability to suspend settled solids. Based on the results of this demonstration, ORNL and DOE concluded a modified PMP would meet project needs for remote sludge mobilization of Gunite tank sludge and reduce the cost of operating and maintaining more complex robotic retrieval systems. The functions and requirements of the system were developed by combining the results and recommendations from the demonstration at PNNL with the requirements identified by staff at ORNL involved with the remediation of the Gunite and Associated Tanks.

The PMP is comprised of a pump chamber, check valve, working gas supply pipe, discharge manifold, and four jet nozzles. The pump uses two distinct cycles, fill and discharge, to perform its mixing action. During the fill cycle, vacuum is applied to the pump chamber by an eductor, drawing liquid into the pump. When the liquid level inside the chamber reaches a certain level, the chamber is pressurized with compressed air to discharge the liquid through the jet nozzles and back into the tank to mobilize sludge and settled solids. A check-valve located at the pump chamber inlet controls the direction of flow. Operating frequency and other parameters can be adjusted, depending on the liquid being mixed. The entire system is controlled and monitored by a laptop computer.

Pulsating Mixer Pump technology was deployed in Tank TH-4 at ORNL to mobilize settled solids during January 2001. The deployment reduced the costs of operation and maintenance of more expensive mixing and robotic retrieval systems. The Effective Cleaning Radius (ECR) of the system was 2.6 m (8.5 ft), resulting in retrieval of approximately 82% of the sludge originally in the tank. The tank cleaning results are consistent with the operations seen during cold testing of the PMP system, and fall well within the risk range established by the Environmental Protection Agency (EPA) based on modeling. Current plans are for the tank to be grouted in place as part of the Federal Facility Agreement (FFA) Remaining Tanks activities.

Additional deployments of the PMP at other DOE sites are being evaluated. For example, the PMP may be adapted for use in the 200 Series single-shell tanks at Hanford, which are similar in size and shape to Tank TH-4.

This report will describe the PMP system and testing program and present results of the deployment in Tank TH-4 at ORNL. At the conclusion of this report, lessons learned and recommendations for improving the PMP system are provided.

ACRONYMS

ARES	American Russian Environmental Services
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
DOE	U.S. Department of Energy
DSR	Decon Spray Ring
ECR	Effective Cleaning Radius
EPA	Environmental Protection Agency
FFA	Federal Facility Agreement
FY	fiscal year
GAAT	Gunite and Associated Tanks
GAAT-TS	Gunite and Associated Tanks Treatability Study
NETL	National Energy Technology Laboratory
ORNL	Oak Ridge National Laboratory
PMP	Pulsating Mixer Pump
PNNL	Pacific Northwest National Laboratory
RI/FS	Remedial Investigation and Feasibility Study

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FIGURES

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1.0 INTRODUCTION

In FY 1998, Pulsating Mixer Pump (PMP) technology, consisting of a jet mixer powered by a reciprocating air supply, was selected for deployment in one of the Gunite and Associated Tanks (GAAT) at Oak Ridge National Laboratory (ORNL) to mobilize settled solids. This technology was identified during FY 1996 and FY 1997 technical exchanges between the U.S. Department of Energy (DOE) Tanks Focus Area Retrieval and Closure program, the DOE Environmental Management International Programs, and delegates from Russia as a promising technology that could be implemented in the DOE complex. During FY 1997, a prototype PMP technology provided by the Russian Integrated Mining Chemical Company, was tested at Pacific Northwest National Laboratory (PNNL) to observe its ability to suspend settled solids. Based on the results of this demonstration, ORNL and DOE staff concluded a modified PMP would meet project needs for remote sludge mobilization of Gunite tank sludge and reduce the cost of operating and maintaining more complex robotic retrieval systems. The functions and requirements of the system were developed by combining the results and recommendations from the demonstration at PNNL with the requirements identified by staff at ORNL involved with the remediation of the Gunite and Associated Tanks. This report will describe the PMP system, testing program, and present results of the deployment in Tank TH-4 at ORNL. At the conclusion of this report, lessons learned, and recommendations for improving the PMP system are provided.

The Mining and Chemical Combine at Zheleznogorsk fabricated the PMP assembly in Russia under a contract with the Russian commercial firm RadioChem Services Company. A total of three PMP's and one control system were fabricated. A single tank riser interface was fabricated by Battelle Pacific Northwest Division to couple the PMP with the tank infrastructure. Battelle also fabricated the decontamination spray ring and transport cradle. Both Battelle and RadioChem Services were under contract to American Russian Environmental Services (ARES) Inc. ARES was the integrating contractor responsible for fabrication and delivery of the PMP system to Oak Ridge and was funded by the National Energy Technology Laboratory (NETL). Installation, checkout, and deployment of the system was funded through the Tanks Focus Area Retrieval and Closure Program. Deployment and disposition of the PMP was coordinated by Bechtel-Jacobs LLC.

This report is organized as follows. Section 2 provides an overview of the PMP systems tested and deployed at ORNL. Section 3 contains the results of testing of an early prototype PMP at PNNL to provide insight for the development of the PMP for ORNL. The results of cold testing in the ORNL Cold Test Facility are provided in Section 4. Section 5 summarizes the initial deployment of the PMP in the United States (U.S.) to mobilize and mix the contents of Tank TH-4. Lessons learned based on this initial deployment and recommendations are provided in Section 6.

As part of the design review process, compliance with appropriate U.S. fabrication standards was an important consideration. The Work Smart Standards (WSS) for Engineering Design applicable to industrial, radiological, and non-reactor nuclear facilities was the governing document identifying required codes and standards for the project. Since design and fabrication of the PMP occurred in a Russian facility that does not work to U.S. standards, full compliance with the existing WSS was not possible. Alternatively, the equipment was fabricated to the appropriate Russian standards, and steps were taken to ensure that the technical intent of U.S. standards was achieved. Pressure tests and inspections of the equipment were conducted in Russia and the U.S. to ensure the integrity of the system prior to deployment.

2.0 PULSATING MIXER PUMP SYSTEM OVERVIEW

The primary function of the PMP is to mobilize and mix solids in tanks filled with sludge, settled solids, and supernatant liquid. The secondary function of the PMP is to keep the solids in suspension while the waste is pumped from the tank. The effectiveness of the mixer is dependent on the size of the tank to be mixed and the characteristics of the waste, but has been tested with simulants thought to bound the actual waste characteristics in key respects.

The PMP is one of several technologies that can be used to remotely mix tank waste, such as jet mixer pumps, pulsed jet mixers, sluicing, air lift circulators, and wave machines (Powell 1996). The advantages of the PMP with respect to alternate technologies are:

- Mechanical simplicity – There are few moving parts in the tank. Since the system does not require a long shaft, like mixer pumps, there is no risk of bearing failure.
- Radioactive waste isolation – The mixing fluid does not leave the tank, which reduces the chances of secondary contamination. The eductor used to apply a vacuum to the pressure vessel is located inside the tank dome, which reduces the risk of transporting contaminated fluid outside the tank.
- Compactness – The PMP has a relatively small cross section and can be deployed through a 57 cm (22.5 in) opening.

The PMP deployed at ORNL is an adaptation of an existing Russian design in use for a radiochemical waste application in Russia; however, the Oak Ridge PMP was designed to accommodate the unique constraints and requirements at the ORNL tank farm. The PMP system at ORNL consists of three major subsystems, the PMP assembly and control system, the Tank Riser Interface (TRI), the Decontamination Spray Ring (DSR). These subsystems are depicted in Figure 2.1 and are discussed in detail in the following sections.

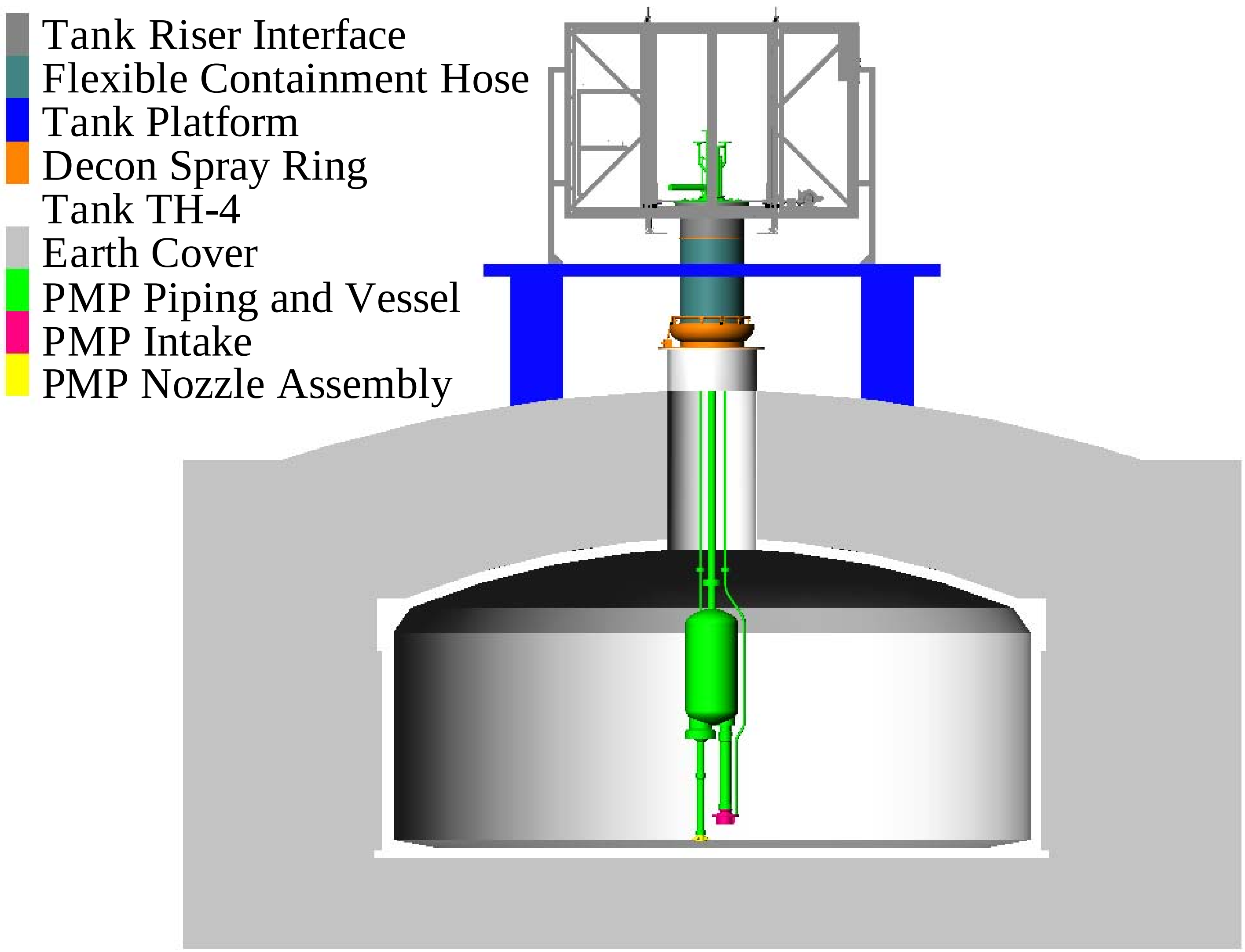


Figure 2.1. Russian Pulsating Mixer Pump Installed in Tank TH-4.

2.1 Pulsating Mixer Pump (PMP)

The PMP assembly is shown schematically in Figure 2.2. The PMP is comprised of a pump chamber, check valve, working gas supply pipe, discharge manifold, and four jet nozzles. The pump uses two distinct cycles, fill and discharge, to perform its mixing action. During the fill cycle, vacuum is applied to the pump chamber by an eductor located in the tank, drawing liquid into the pump. When the liquid level inside the chamber reaches a certain level, the chamber is pressurized with compressed air to discharge the liquid through the jet nozzles and back into the tank to mobilize sludge and settled solids. The maximum working pressure of the PMP is 1586 kPa (230 psi). A check-valve located at the pump chamber inlet controls the direction of flow. The PMP can be rotated through a 90º arc in alternating clockwise and counterclockwise directions using a pneumatic cylinder to sweep the entire bottom of the tank. Figure 2.3 shows the mixing nozzles and intake for the PMP. On the top, various shut-off valves are operated in conjunction with an electromechanical air-distribution valve to direct either compressed air or vacuum to the PMP chamber.

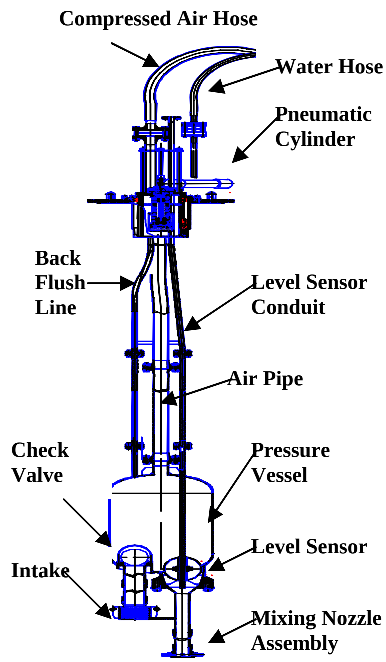


Figure 2.2. Schematic of Russian PMP.

Figure 2.3. PMP Intake and Discharge Nozzles.

Tank liquid is drawn into the pump chamber through a coarse screen and check valve assembly connected to the bottom of the pump chamber. In the event of a plug in the inlet screen, wash water can be used to back-flush the screen and check valve. A level sensor located inside the chamber is used to control the vacuum and discharge cycle durations. Operating frequency and other parameters can be adjusted, depending on the liquid being mixed. The entire system is remotely controlled and monitored by a laptop computer using Labview™ software.

2.2 Tank Riser Interface (TRI)

The primary function of the tank riser interface (TRI) system is to provide an interface between the PMP and the tank riser, the service support platform, site utilities (electrical, air, and water), and the control system. For the deployment at ORNL in Tank TH-4, the TRI Frame was connected to the ORNL service platform above the tank. The frame support legs can be used to adjust the insertion depth of the PMP to accommodate various tank depths. Once installed, the mounting flange of the PMP can be raised and lowered mechanically without breaking containment to effectively mix different tank levels. The TRI includes mounting hardware for the control system valves and an enclosure, which protects the hardware from environmental debris and permits access to any out-of-tank components requiring routine maintenance. The TRI includes lifting lugs to allow the PMP to be lifted with a single crane and inserted into a riser. The TRI vertical drive system can be used to adjust the height of the PMP mixing nozzles so that the jets can be concentrated from 2.3 cm to 58 cm above the tank floor.

Since the PMP will rotate (oscillate) while connected to the control valves by hoses, the support structure for the control valves was designed to avoid interference with the rotation of the PMP and limit stress and wear on the hoses and associated connections. A solid model of the TRI is shown in Figure 2.4. Figure 2.5 shows the TRI after the installation of the control system and PMP. The major system components of the TRI are discussed below.

- PMP Frame Base Plate: The PMP is mounted to a thick, rectangular plate. This part includes a long circular section to store a 9.1 m (30 ft) long containment bag that will be used to encapsulate the pump during pump extraction.
- Mechanical Lifting Drive: The PMP Frame Base Plate is attached to 4 screw-type Duff Norton™ mechanical actuators to allow the PMP depth to be varied over a 56 cm range. The mechanically coupled actuators are driven through rotating shafts and mitre gear-boxes with a ½ HP Duff Norton motor. The lead-screw arrangement synchronizes motion to ensure that a level pump orientation is maintained. After the PMP is moved to the desired operating depth, a brake on the actuator motor will hold position to avoid creep. A control switch on the PMP Support Frame will operate the motor. Limit switches are used to control the range of motion of the drive unit. The linear actuators in the vertical drive system can exert a force of up to 8900 N each. A torque limiting clutch on the motor output limits the maximum force while still allowing the system to raise the PMP. Without a torque limiter, the vertical drive system could exert a force on the tank bottom greater than permitted by ORNL safety requirements.

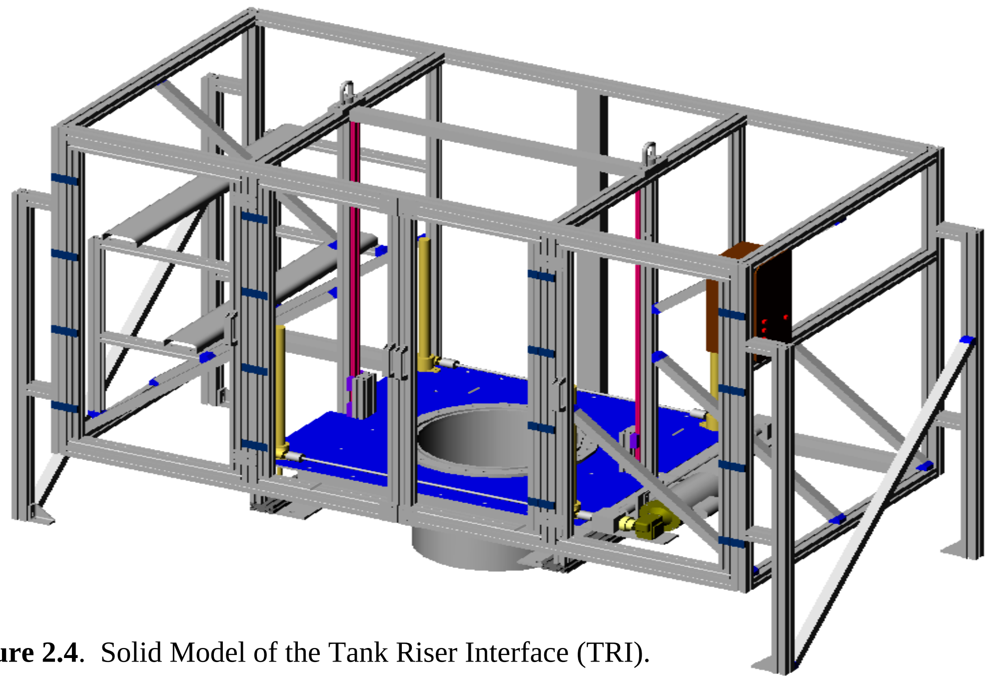


Figure 2.4. Solid Model of the Tank Riser Interface (TRI).

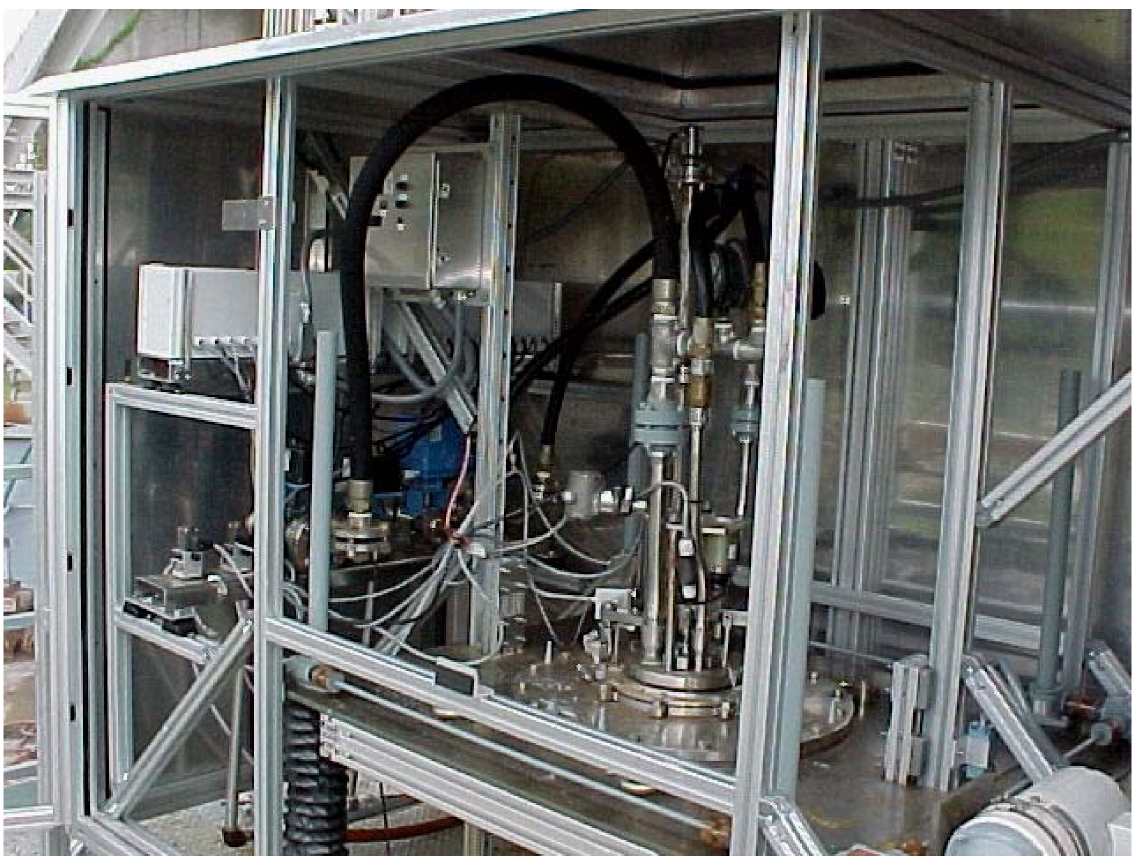


Figure 2.5. TRI after the Installation of the Control System and PMP.

- PMP Support Frame: A modular frame is the primary support structure for the PMP, drive system, mounting plate, control valves, and electrical boxes. The frame includes a vertical bearing to limit lateral forces on the mechanical lead screws. The frame legs can be adjusted to accommodate different PMP insertion lengths. The support frame was constructed with Bosch™ aluminum structural components to allow maximum flexibility for re-configuration and to reduce costs associated with welding and finishing processes. The PMP frame is covered with panels to protect components from debris and prevent personnel from contacting moving parts. The frame interior can be accessed by three doors on the front of the PMP.

2.3 Decontamination Spray Ring (DSR)

The function of the decontamination system is to remove surface contamination from the in-tank components of the PMP during removal of equipment from the tank. Process water or other commonly used decontamination fluid may be used for system decontamination. The DSR (Figure 2.6) is designed to mount directly to the tank riser using a mounting flange and includes mounting holes for the spray nozzles and hoist rings. Six 65° fan-type spray nozzles are mounted around the circumference of the DSR to allow the PMP in-tank components to be washed during equipment extraction. The jets provide complete coverage of the equipment. The jet nozzle assemblies include a nozzle holder and flow straightener. A manual control valve connected to the inlet to the manifold can be closed when the spray ring is not in use to maintain tank containment. The manifold can be connected to a high-pressure pump or lower pressure supply with proper choice of nozzle size. All components are rated to at least 13800 kPa (2000 psi). Internal decontamination will be accomplished by the fresh water back-flushing system of the PMP.

Figure 2.6. Decon Spray Ring.

A flexible vacuum hose was used to connect the PMP Frame Base Plate to the Decontamination Spray Ring. This accommodated the 56 cm motion of the linear drive system. The hose was constructed of double-ply neoprene impregnated fabric and is 155 cm (61 in) in diameter: the hose has an open length of 76 cm or longer, depending on deployment insertion length of PMP, and a closed length of 20 cm. The hose has a vacuum rating 1.3 cm Hg. Various alternatives were considered for the flexible containment, including the use of elastomer expansion joints, metal bellows, and expansion joints. The vacuum hose was selected because it was the cheapest alternative that met the requirement. The hose can also be left in place during decontamination to serve as a splatter guard.

2.4 Deployment Cradle

The purpose of the Deployment Cradle is to support the PMP piping and frame when the system is transferred from the vertical to the horizontal orientation (see Figure 2.7). The cradle includes pins to help position the frame on the upper mounting surface. The deployment sequence described below is graphically depicted in drawing H-3-308920, page A-3 located in Appendix A. After the two long pins are aligned into their respective holes, the PMP is lowered and the other pins are aligned automatically. This design avoids the need to align all pins simultaneously. This arrangement has been used remotely in a West Valley hot cell to assemble various pieces of equipment using a camera and direct line of vision from a 6.1 m (20 ft) high vantage point. For this application, the visibility of the pins from the crane was an important consideration, since the pins will be more than 9.1 m (30 ft) above ground. The cradle includes a pivot point to allow the cradle to rotate. A retaining pin prevents rotation while the cradle is in the vertical position. Once the pins are aligned, operators using a manual lift physically bolt the frame to the cradle.

Figure 2.7. PMP Deployment Cradle at ORNL Cold Test Facility.

3.0 PMP DEMONSTRATION AT PNNL

During FY 1997, the operation of an early version of the PMP was demonstrated in a 5.7-m (18.75-ft) diameter tank at PNNL (Enderlin 1997). The purpose of the demonstration was to provide an initial evaluation to determine whether the PMP technology merited further consideration for applications to the US DOE waste tanks and to provide insight for the development of a more extensive test matrix. The PMP operation was visualized using medium grain sand (1 to 2.4 mm) spread over the tank bottom with water as a supernatant liquid. The size of the sand was selected to be large enough so that the PMP jets would not suspend the sand when the system was operating at the control settings selected for the demonstration. The purpose of the sand was to provide flow visualization of the influence that the PMP jets have on the test tank floor. The PMP for this test contained two diametrically opposed, 8-mm (0.31-in) diameter nozzles.

Two tests were conducted with the PMP remaining stationary (not rotating). The first was conducted with the nozzles oriented in a north-south direction. During this test, the period was 21 seconds and the vacuum and supply pressures were 77 kPa absolute (11.1 psia) and 557 kPa gauge (80.7 psig), respectively. The PMP was run for 9 minutes and then the cleared area on the tank floor was measured. The dimensions for the observed area of jet influence on the bottom of the tank are presented in Table 3.1 and Figure 3.1. The first jet pulse cleared the floor of sand out to a distance of approximately 1.5 m (5 ft) and on the second pulse to about 1.8 m (6 ft). After the first four pulses, the growth of the footprint slowed considerably. After nine minutes of run time, the jets were still moving sand on the bottom of the tank causing the cleared area to grow at a slow rate.

TABLE 3.1. Dimensions of Jet Footprint created by Pulsating Monitor on Tank Floor.

Test 1 Results

DIMENSION	DISTANCE, METERS	DISTANCE, IN.	DIMENSION	DISTANCE, METERS	DISTANCE, IN.
A	2.34	92	F	1.6 - 1.7	63 - 66
B	0.79 - .81	31-32	G	0.20	8
C	1.57 - 1.60	62-63	H	0.25	10
D	2.59	102	I	0.08	3
E	0.76 - 0.79	30-31	J	0.08	3

Test 2 Results

DIMENSION	DISTANCE, METERS	DISTANCE, IN.	DIMENSION	DISTANCE, METERS	DISTANCE, IN.
A	2.51	99	H	0.08	3
B	0.60	24	G	0.08	3
C	1.78 - 1.83	70-72			

For the second test, the PMP was rotated 90 degrees so that one of the nozzles would erode a thick layer of sand. The pulse rate was maintained at 21 seconds, and the time average pressures were 78 kPa absolute (11.4 psia) and 556 kPa gauge (80.7 psig) for the vacuum and supply pressure, respectively. This test was run for approximately four minutes. The dimensions for the cleared area created by the jet to the west of the PMP (i.e., through the thick layer of sand) are also presented in Table 3.1.

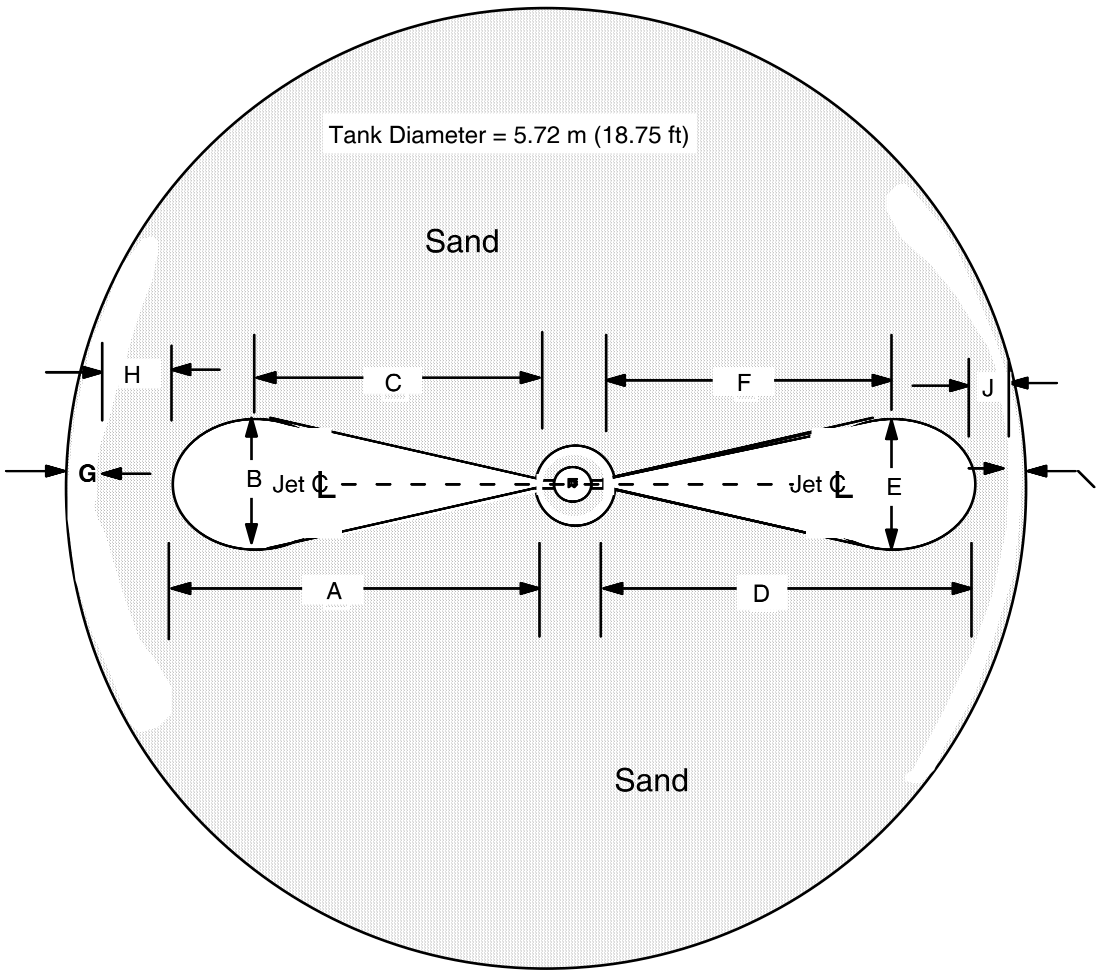


Figure 3.1. Diagram of Jet Footprint created by Pulsating Monitor on Tank Floor.

4.0 COLD TESTING AT ORNL

Cold testing consisted of pre-test inspections, functionality tests, and performance tests. A discussion of these tests is provided below.

4.1 Pre-test Inspections

Pre-test inspections were conducted to assess the quality of fabrication of the system components. Pre-test inspections included a review of fabrication documentation (quality assurance records, weld inspections, as-built drawings), visual and ultrasonic analysis, materials composition analysis, and hydrostatic tests. In general, the equipment was well designed and fabricated to the required specifications. The following are items required resolution prior to testing:

- Weld repairs on the pressure vessels for PMP's 2 and 3 due to undetected weld defects.
- Clean-up of weld slag on PMP 1 level sensor thimble.
- Replacement of broken and loose components on TRI and PMP 1.
- Installation of grease fittings on Deployment Cradle pivot points.
- Rewiring of TRI drive motor brake.

4.2 Functionality Tests

Tests were conducted to assess the functionality of the TRI, DSR, control system components, transport cradle, support fixtures, and contamination control features. All hardware components performed satisfactorily with some minor modifications and replacement of select components to improve operation and reliability.

- Relays were added to control modules.
- Emergency stops were added.
- Limit switches on the TRI were replaced with waterproof versions.
- Control system program was revised to improve functionality and simplify operation.
- The lifting points for the TRI were moved from the top of the frame to the TRI base plate so that the combined PMP and TRI could be lifted as a single unit.

4.3 Performance Tests

Performance testing was performed in the ORNL Cold Test Facility prior to deployment of the PMP to observe the operation of each PMP in a simulated waste tank of similar dimensions to Tank TH-4. These tests assessed the performance of the system in the following areas: debris tolerance, mixing efficiency, decontamination effectiveness, and tank cleaning radius. For the performance tests, the PMP was suspended above a 6.1-m (20-ft) diameter plastic-lined test tank constructed of cinder blocks (see Figure 4.1). Performance test results are summarized in the following sections.

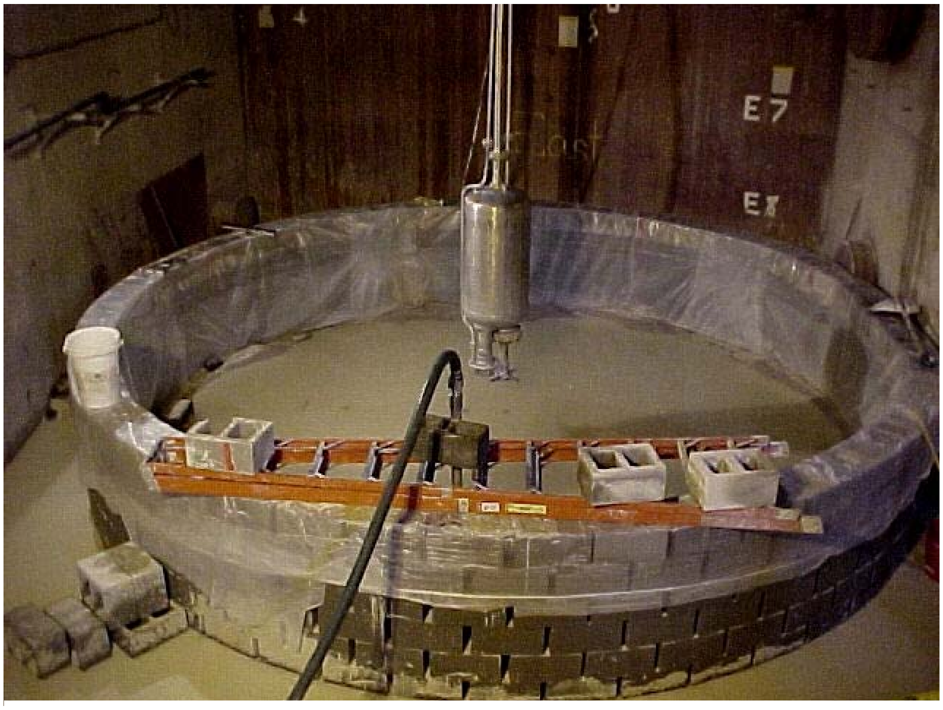


Figure 4.1. PMP Suspended above a 6.1-m (20-ft) diameter plastic lined Cinder Block Test Tank.

4.3.1 DSR Performance Test

During this test, the ability of the DSR waterjets to clean contaminated surfaces of the PMP was evaluated. Kaolin clay simulant was applied to the PMP piping arrangement. The drive table was then used to raise the PMP during operation of the DSR waterjets. A range of pressure was tested, from 690 to 10,300 kPa (100-1500) psi. It was found that the DSR cleaned the piping of all visible sludge using an operating pressure of 3450 kPa (500 psi).

4.3.2 PMP Debris Tolerance Test

The test was conducted to evaluate the tolerance of the PMP to various types of debris that might be present in Tank TH-4. The following debris was sequentially inserted into the test tank near the pump intake: plastic bags, rubber gloves, rope, tie wraps, electrical wire, and tape. The pump was operated for a minimum of 2 hours. The presence of the debris did not cause any problems or blockages, and no physical intervention was required to allow operation to continue.

4.3.3 Cleaning Radius Tests

This test evaluated the effective cleaning radius (ECR) for the PMP nozzles using four different nozzle sizes (11, 12, 14, and 16 mm) and various simulated waste types such as medium grain sand, 1 cm gravel, and kaolin clay. The ECR was 2.1 to 2.4 m (7 to 8 ft) with the PMP operating with 90 psig air supply and stationary. The ECR using oscillating jets was found to be approximately the same as the ECR achieved with a stationary jet. The nozzle size did not dramatically affect the ECR for the range of materials tested.

4.3.4 Mixing Retrieval Testing

Sludge simulant representative of the material expected to be in Tank TH-4 was placed in the bottom of the test tank. Mixing and pumping tests were conducted using various water depths, from 28-91 cm, with the PMP positioned approximately 2.5 cm from the floor of the test tank. The clay-sand mixtures were easily mobilized to the outside walls of the test tank after 45 minutes of mixing time. A positive displacement diaphragm pump was placed near the circumference of the tank to remove the slurry during the mixing process. Very little sludge remained in the tank after the pumping operation was completed.

5.0 DEPLOYMENT AT GAAT TANK TH-4

The ORNL Gunite and Associated Tanks Treatability Study (GAAT TS) project was initiated in FY 1994 to support a record of decision in selecting from seven different options of technologies for retrieval and remediation of these tanks. This decision process is part of a Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) Remedial Investigation and Feasibility Study presented to DOE and the Tennessee Department of Environment and Conservation. As part of this decision process, new waste retrieval technologies were evaluated at the 7.6-m (25-ft) diameter Gunite tanks in the North tank farm.

The PMP was chosen for deployment in Tank TH-4 at ORNL. TH-4 is 6.1 m (20 ft) in diameter, with a total working capacity of 52,996 liters (14,000 gallons). Design information indicates a wall thickness of 15.2 cm (6 in) and a 7.6 cm (3 in) sprayed floor. It is expected that an asphalt layer and additional 3.8 cm (1.5 in) of gunite was added to the floor and walls as in the South Tank Farm tanks. The tank has a vertical sidewall height of 2.0 m (6.5 ft) and a dome height of 0.8 m (2.6 ft).

The tanks contain radioactive chemical waste that consists of settled sludge covered by a layer of aqueous supernatant liquid with a vaporous air space above the liquid. Prior to deployment of the PMP, the tank contained 20,800 liters (5,500 gallons) of sludge covered with 1.22 m (4 ft) of liquid. The average sludge depth was 0.9 m (2.5 ft). The following information was the "best estimate" based on (Martin Marietta Energy Systems 1994). The solid waste is non-heat generating, insensitive to impact, rubbing or abrasion. The pH ranges from 7 to 11. Organic compounds may be expected in the wastes, as are nitrates, phosphates and sulfates. The solid waste is a mixture of silt, clay, pasty particles, some crystallized solids (formed during storage), lumps of Gunite (eroded from the tank walls), and miscellaneous debris (plastic bags, coveralls, and metal cans). Some waste forms may be highly abrasive. Bulk slurry density ranges from 1.0 gram/ml to 1.47 gram/ml have been measured in samples. Solids density may exceed 2.0 gram/ml. Concentration in the undisturbed sludge of up to approximately 45 weight percent solids was expected. Particles ranging from less than 10 micron to approximately 9.5 mm (3/8 in) may require mobilizing and removal. The temperature ranges from 4° to 27°C (40° to 80°F) and radiation emissions were estimated to range from 100 mR/hr to 50 R/hr, with point sources in excess of 150 R/hr.

The liquid waste was primarily water, containing some soluble material from the tank waste. The density of the liquid was in the range of 0.99 gram/ml to 1.06 gram/ml and the viscosity was approximately equal to that of water. A thicker transition phase close to the waste surface may be present along with a density gradient. The pH ranges from 7 to 11 and the conductivity from 10 to 20 ohm/cm. Toxic organic compounds (TOC) are present in concentrations of 200 to 8500 µgram/gram.

5.1 Summary of Mixing and Retrieval Campaign

The mixer and associated equipment were installed in Tank TH-4 early in FY-01 and were not operated until DOE readiness review approval on Thursday, 1/11/01. The tank was initially full to capacity with supernatant fluid due to groundwater in-leakage. On the evening of 1/11/01, supernatant fluid was removed down to the initial operating depth of 1.71 m (5.6 ft), including sludge and supernatant fluid. Safety documentation initially required a minimum of an equal volume of fluid to sludge, which was expected to be 76.2 cm (30 in) deep. Due to waste volume generation constraints, it was not possible to remove additional liquids to observe the sludge surface prior to mixing. Also, the in-tank camera had failed and had to be replaced on the morning of 1/12/01.

An air-operated double diaphragm pump assembly was fabricated at ORNL and installed to transfer the waste as a slurry via a temporary, double contained pipeline to the W-6 valve box in the South Tank Farm. The waste was directed from the valve box into Tank W-23 at Building 2531. An air-powered double diaphragm pump was used for the transfers (3.81 cm diameter Sandpiper model SB1-1/2-A, manufactured by Warren Rupp). The transfer pump inlet was located on a pile of sludge (estimated to be 25-40 cm deep), which initially limited the minimal level that could be achieved during pump-down. The inlet was later repositioned to within 10 cm of the tank floor for the final transfers.

The initial plan was to mix a minimum of 4 hours on Friday, 1/12/01, and collect a grab sample of the slurry from the tank to verify the Waste Acceptance Criteria (WAC) for the waste system was met before transferring. Due to delays experienced from replacing the camera and completing the leak test, noise check, and start-up procedure, mixer operation did not commence until mid afternoon. After operating for approximately 30 minutes, the mixer shut down automatically due to an 'overdue fill', which indicated that the vessel was taking an excessively long time to fill. This parameter was set initially at 60 seconds. The system was restarted and experienced the same condition. Back-flushing restored operation for 5 to 10 cycles. Adjusting the eductor supply pressure and/or the percent open position on control valve KV3 did not seem to affect this operation significantly. After several attempts to restart the mixer, the sample was collected from the tank following approximately 2 hours of intermittent mixing. The sample had a bright greenish-yellow color (similar to the sludge), and an almost slush-like consistency. Radiation levels were negligible (expected since the sludge primarily contains only alpha emitters). The system was flushed and shut down at dark (following the sample collection).

The mixing campaign was resumed on Saturday, 1/13/01, with the same time-out shut downs occurring frequently. Isolating the purge air supply manually while filling and varying the operating pressures didn't appear to affect the operation. The weather remained overcast/drizzling with temperatures ranging from 2 to 7ºC (35 to 45ºF). After approximately 2 hours of mixing, the retrieval pump was activated to begin the transfer of mixed sludge/supernate. One possible cause of the problem was that the mixer inlet was plugging (an organic layer was floating on top of the supernate following the initial mixing on Friday, and was still present Saturday morning). Similar material was seen in the other GAAT tanks. The tank level was pumped down to the PMP inlet elevation, but the screen was clean. The mixer was lowered in 10 to 15 cm (4 to 6 in) increments until the bottom of the tank was reached (with the nozzles rotated during all operation to this point). The remaining supernate was then removed to observe the sludge profile. While the mixer was shut down, adjustments were made to tighten two loose bolts on top of the mixer where the air distributor valve stem passes through the top of the air distributor housing. Water was noticed leaking from this area during flushing. After tightening these bolts, the air distributor valve would not close due to excessive friction. Normally, gravity load initiated the closure cycle. Additional counterweights were added to the trombetta lever arm, but the trombetta was not able to lift the air distributor valve. Shifting the weights and loosening the two bolts that were previously tightened around the shaft seal achieved a workable balance, but intermittent sticking of the air distributor valve was apparent for the remainder of the operation. Lubricating oil was added to the shaft in case there was a dry seal and/or rough surface.

Operations began again on Sunday, 1/14/01, with the return of supernate to Tank TH-4 from the Supernate Supply Tank W-8. Once a level that covered the PMP inlet was reached, the mixer was restarted with the nozzles in a fixed position at 0 degrees. For the remainder of the day, the mixer was operated in a fixed nozzle position with the angle changed by 15 to 20º following each pump out. The mixer continued to operate intermittently with overdue fill cycles, followed by flushing and restarting. The mixer was operated for approximately 10 hours intermittently on 1/13/01 and 1/14/01. To remedy the problem with the air distributor valve, the air distributor valve was acquired from unit 2; but since the replacement operation required a significant disconnect/disassembly process, a decision was made that the limited time available would be best used by improving the operation of the original valve. The weather remained overcast with temperatures ranging from 4 to 10ºC (40 to 50ºF).

On Monday, 1/15/01, the tank was refilled to approximately 62 cm (24 in) deep with supernatant fluid from Tank W-8. The planned retrieval operation was to mix approximately 30 minutes, pump down to the minimum mixer operating level, continuing to mix for 15 to 20 minutes, and refill the tank to approximately the 0.61 m (2 ft) level with the mixer operating as continuous as possible. The pump-down rate was approximately 190 liters/minute (50 gallons/minute). By late morning, the weather began to clear, and the temperature rose to 10 to 13º C (50 to 55ºF) by the afternoon. The mixer was operated in stationary locations during the morning, and rotated in the afternoon. Approximately five of these pump in/out cycles were completed with the mixer operating as continuous as possible for approximately 10 hours. In the afternoon, the mixer operated for over 1 hour with no timing out, was stopped and flushed and restarted and operated for over an hour again until it was stopped when the minimum operating level in TH-4 was reached. The system was then flushed out for the final time.

The residual slurry in the tank was approximately 10 cm deep over the entire floor, corresponding to the minimal pump depth, with the retrieval hose inlet resting on the floor where all the sludge was removed. A ring of sludge 30 to 60 cm wide remained around the perimeter of the tank up to approximately 38 cm deep. This material began to slump into the tank at the conclusion of the pump-out. The initial photos are of the slumped material (see Figure 5.1). The nozzles were positioned within 1.2 to 2.5 cm of the tank floor for the final transfers.

Additional material could probably be removed by utilizing additional mixing and pump-out cycles; but since DOE and the site regulators concluded that the residual waste volume met the minimal closure criteria, the mixing operation was suspended. The solid material in grab samples appears to settle fairly rapidly to a distinct sludge/clear liquid interface. The sludge has more of a gel or slime consistency than the particulate from other GAAT tanks, and settled into two distinct layers more than a gradual transition. Samples taken from Tank TH-4 readily went into suspension when the sample bottle was shaken.

It was desirable to operate the mixer for extended periods of time (up to 24 hours), but this was not possible due to problems with the air distribution valve. However, from cold test observations, it appears that the maximum concentration in the supernate would be achieved after approximately 45 minutes of operation when using a sand/kaolin clay simulant. The preliminary analytical results seem to show most particles were smaller than 100 micron and the majority of the solids are soluble in the supernate.

Figure 5.1. PMP in Tank TH-4 after Conclusion of the Mixing Campaign.

5.2 Retrieval Data Analysis

5.2.1 PMP Rotation

The PMP was operated in both static and rotating modes. In the rotating mode, the PMP was moved through a 90° arc. Erratic actuation was observed near the end of the 90° arc (around 70 to 75°). It is suspected that the air pressure to the air cylinder was set too low to complete the 90° arc in one smooth motion. Rotation began at approximately 3 to 4°, and was steady through approximately 70 to 75°. It became erratic and jumped up to 90° before returning to the 'zero' position. The rotation rate was set to approximately match the discharge time for each pump cycle.

5.2.2 Operating Pressures

The air supply pressure to the PMP for the discharge cycle was varied during the operation from 344 to 621 kPa (50 to 90 psig). The purge time was typically from 7.2 to 7.4 seconds. The eductor pressure was varied from 138 to 324 kPa (20 to 47 psig), but was primarily operated in the range of 207 to 241 kPa (30 to 35 psig).

5.2.3 Solid Monitoring Test Loop Data

The retrieved slurry was processed through the Sludge Conditioning – Solid Monitoring System to monitor the pressure, mass flow rate, density, and particle size distribution of the slurry. Density and mass flow rate, which were of primary interest, were monitored by an Endress/Hauser coriolis flow meter. The instantaneous mass flow and density during each day of the campaign is summarized in the following figures. Note that the measured mass flow was approximately zero during periods of time when supernatant fluid was recycled back into the tank. This was due to the fact that the mass flow meter did not respond to reverse flow.

- Figure 5.2: Initial Transfer of Supernate (1-11-01). The average density during transfer was 1.004 gram/ml.
- Figure 5.3: Initial Transfer, Recycle, and Transfer (1-13-01). The average density during transfer was 1.023 gram/ml.
- Figure 5.4: Three Transfer/Recycle Operations (1-14-01). The average density during transfer was 1.045 gram/ml.
- Figure 5.5: Four Transfer/Recycle Operations (1-15-01). The average density during transfer was 1.040 gram/ml.

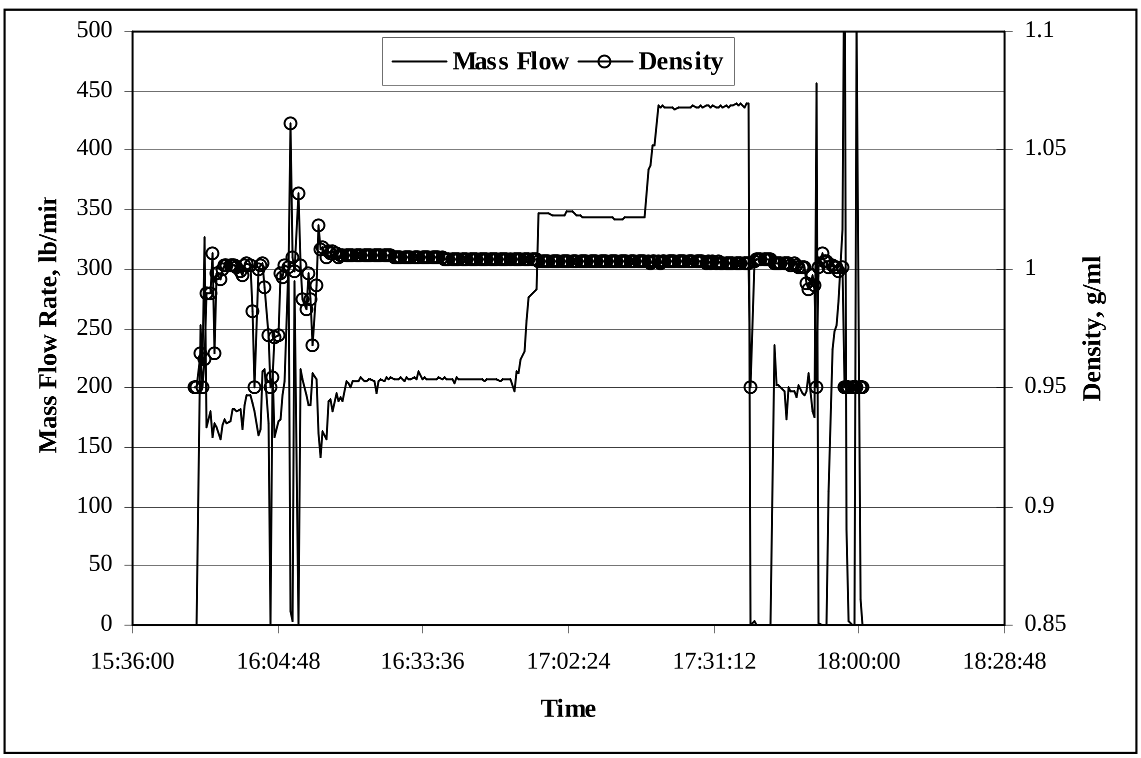


Figure 5.2. Tank TH-4 Waste Transfer Summary (1-11-2001).

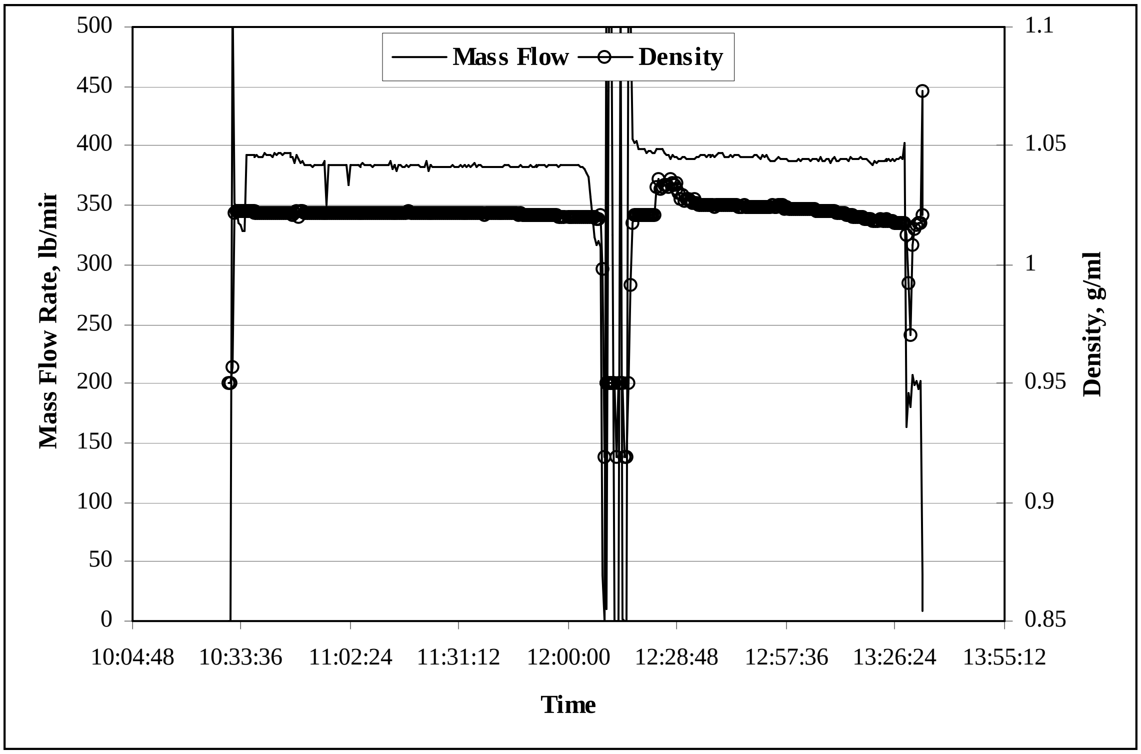


Figure 5.3. Tank TH-4 Waste Transfer Summary (1-13-2001).

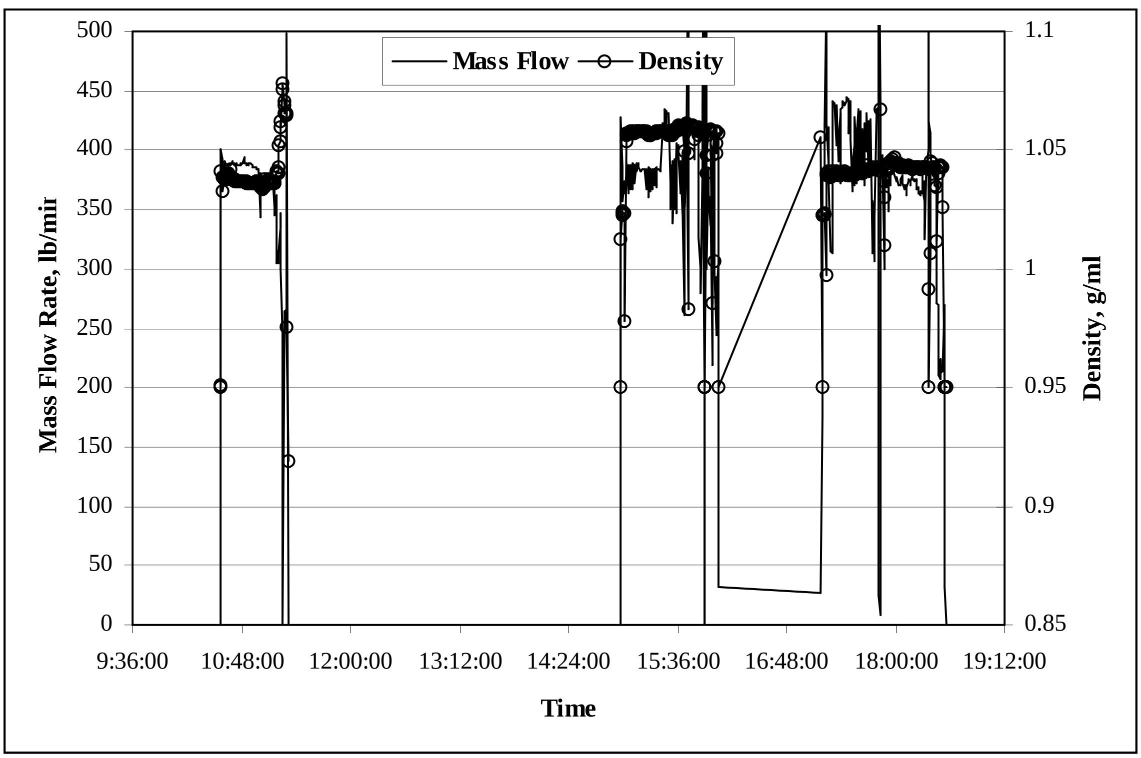


Figure 5.4. Tank TH-4 Waste Transfer Summary (1-14-2001).

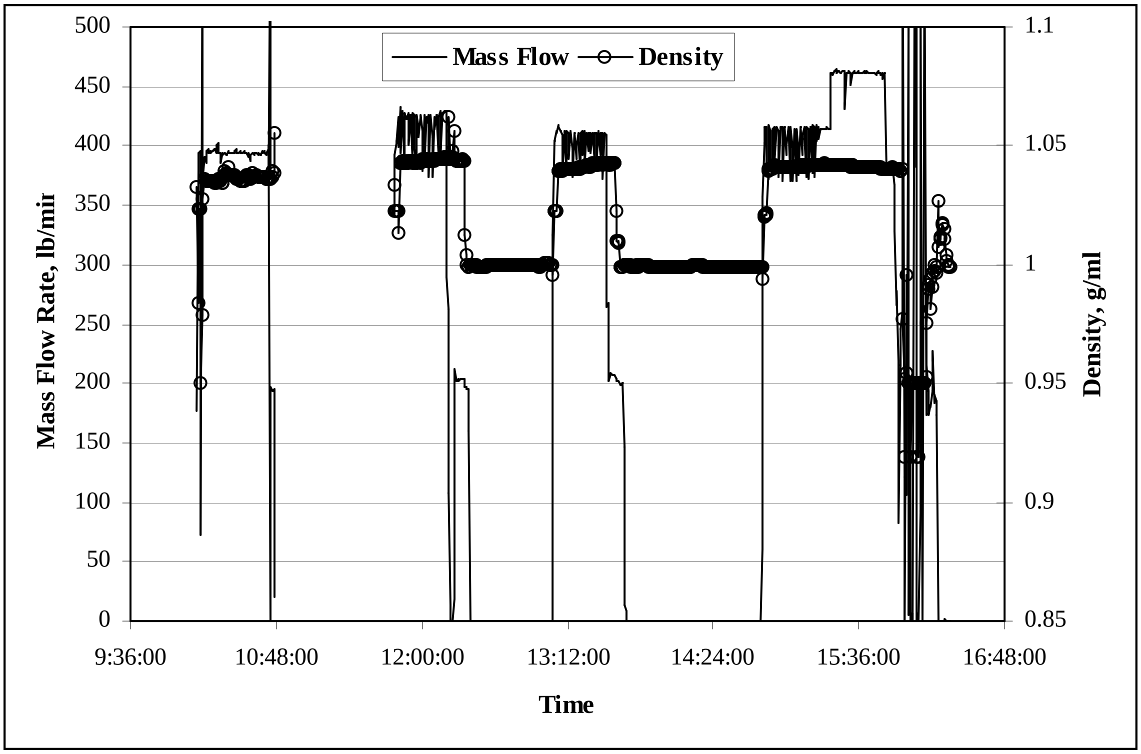


Figure 5.5. Tank TH-4 Waste Transfer Summary (1-15-2001).

5.3 Residual Waste Volume Estimate

The final tank inspection was conducted with the in-tank video camera, in conjunction with the tank level instrument and vertical drive table capability of the PMP system. The residual sludge volume was calculated based on this data and presented in Table 5.1. The ECR of the system was 2.6 m (8.5 ft), resulting in retrieval of approximately 82% of the sludge. It was conservatively assumed the 10 cm (4 in) of residual slurry in the center of the tank is 50% sludge (i.e., 5 cm), and that the residual at the tank perimeter is a uniform 0.4 m (1.5 ft) width, rather than the 0.15 m (.5 ft) to 0.4 m (1.5 ft) observed. Also, no credit was taken for the slope of the tank floor up to the wall around the perimeter in the residual calculations (calculations are based on a flat tank floor). These tank cleaning results are consistent with the operations seen during cold testing of the PMP system, and falls well within the risk range established by the Environmental Protection Agency (EPA) based on modeling. Current plans are for the tank to be grouted in place as part of the Federal Facility Agreement (FFA) Remaining Tanks activities.

5.4 Suggestions for Design Improvements and Lessons Learned

- The charge time varied significantly due to problems with seating of the air distributor valve. Typical charge times during the last day of operation when the air distributor valve appeared to be operating properly were around 32 to 35 seconds, but continued to vary up to 70 seconds. Following a flush and restart of the PMP, a 35-second charge time was achieved for 3 - 4 cycles, then the charge time increased by several seconds per cycle until timing out after 5 - 10 charge cycles. The problem appears to be independent of operating pressure (charge and discharge), and manual operation of the discharge air supply didn't resolve the situation. It did appear to be temperature dependent, as the performance of the valve improved in warmer temperatures. A small weep hole was added to the air distribution valve housing for units 2 tojason.legore@ccivalve.ch 3 to limit the vacuum level in the valve and prevent excessive vapor from condensing in the valve and freezing. This design change, not incorporated in the deployed unit (PMP-1), could have eliminated the problems associated with the distribution valve.

TABLE 5.1. Residual Sludge Volume Estimate for TH-4 after Completion of PMP Campaign.

INITIAL SLUDGE ESTIMATE

Tank Diameter	6.10	m			
	20	ft			
Original Sludge Depth[1]:	81.28	cm	Sludge Volume	23718	liters
	32	in		6266	gallons

RESIDUAL SLUDGE VOLUME

	Diameter		Sludge Depth		Volume	
	(m)	ft	(cm)	in	(liters)	gallons
General Area	5.18	17	5.08	2	1071	283
Perimeter, Outer	6.10	20	38.1	15	11118	2937
Perimeter, Inner	5.18	17	38.1	15	8033	2122
			RESIDUAL VOL, liter		**4156**	**1098**

[1] Reference ORNL/ER-13 for sludge volumes and analytical data

- The deployment schedule was extremely tight and did not allow a great deal of time for fine-tuning of the system. It is believed that while not required by regulatory closure criteria, more solids could have been removed from the tank with additional mixing and pump-out cycles. This is supported by the fact that the density of the slurry transported out of Tank TH-4 was fairly steady during the final transfer. A decrease in specific gravity would indicate that the limits of mobilization had been reached.
- Based on the weld inspections conducted on the PMP pressure vessel, the maximum operating pressure was de-rated from 230 psi to 90 psi. Operating at higher pressure would have increased the effective cleaning radius of the jets and resulted in lower residual sludge levels.

6.0 CONCLUSION AND RECOMMENDATIONS

Pulsating Mixer Pump technology was deployed in Tank TH-4 at Oak Ridge National Laboratory to mobilize settled solids in Tank TH-4 during January 2001. The deployment reduced the costs of operation and maintenance of more expensive mixing and robotic retrieval systems. The ECR of the system was 2.6 m (8.5 ft), resulting in retrieval of approximately 82% of the sludge originally in the tank. The tank cleaning results are consistent with the operations seen during cold testing of the PMP system, and falls well within the risk range established by the EPA based on modeling. Current plans are for the tank to be grouted in place as part of the FFA Remaining Tanks activities.

Additional deployments of the PMP at other DOE sites are being evaluated. For example, the PMP may be adapted for use in the 200 Series single-shell tanks at Hanford, which are similar in size and shape to Tank TH-4.

REFERENCES

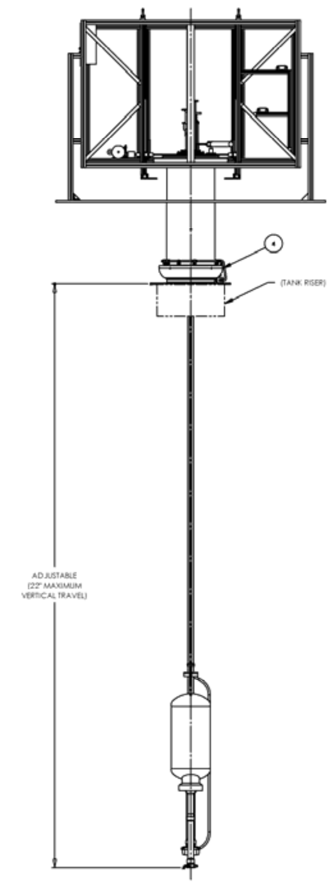
1. Enderlin, CW, OD Mullen, and G Terrones. 1997. *Performance Evaluation of the Quarter-Scale Russian Retrieval Equipment for the Removal of Hazardous Waste.* PNNL-11740, Pacific Northwest National Laboratory, Richland, Washington (available at http://www.tanks.orgram/).

2. Powell, MR. 1996. *Industrial Mixing Techniques for Hanford Double-Shell Tanks*. PNNL-11021, Pacific Northwest National Laboratory, Richland, Washington (available at http://www.tanks.orgram/).

3. Martin Marietta Energy Systems, Inc. 1994. *Results of Fall 1994 Sampling of Gunite and Associated Tanks at the Oak Ridge National Laboratory,* Oak Ridge, Tennessee, ORNL/ER/Sub/87-99053/7.

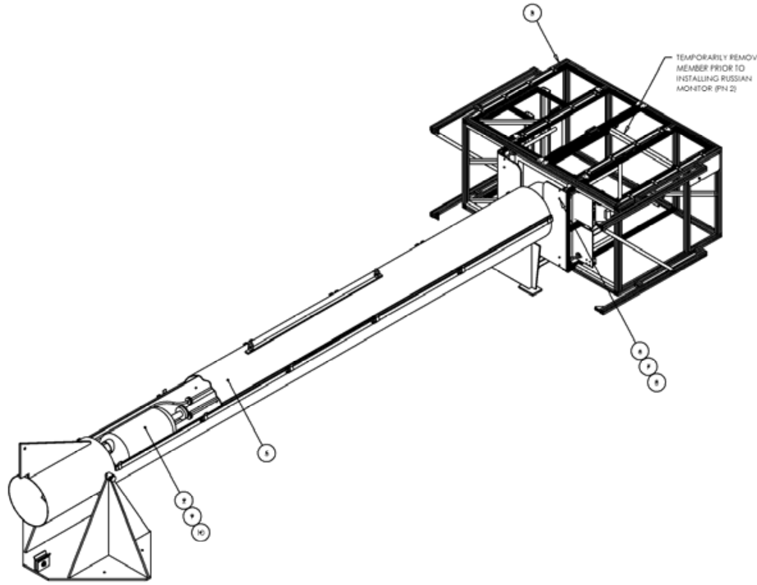
Appendix A

Pulsating Mixer Pump Assembly Drawing and Deployment Sequence



PUMP IN VERTICAL OPERATING POSITION

NOTE: CRADLE ASSY (PN 5) MUST BE REMOVED AS SHOWN.



(1) ASSEMBLY (3D ISOMETRIC VIEW)

NOTE: PUMP IN TRANSPORT CRADLE.
SEE SH 2 FOR DEPLOYMENT SEQUENCE.

QTY	PN	DESCRIPTION	MATL/REF
X	1	ASSEMBLY	
1	2	RUSSIAN MONITOR (PUMP), SUPPLIED BY RUSSIAN FEDERATION MINISTRY FOR ATOMIC ENERGY MINING AND CHEMICAL COMBINE	M2 260 00 00 AD
1	3	FRAME ASSEMBLY	H-3-308921
1	4	DECON SPRAY RING ASSEMBLY	H-3-308922
1	5	CRADLE ASSEMBLY	H-3-308923
4	6	BOLT, 3/4-10UNC-2A x 1.5 L	18-8 SST
4	7	HEX NUT, 3/4-10UNC	18-8 SST
4	8	LOCK WASHER, 3/4"	18-8 SST
AR	9	TEFLON JOINT SEALANT, #4502K24	McMASTER-CARR
16	10	HEX NUT, 1/2-13UNC	18-8 SST

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(UNLESS OTHERWISE SPECIFIED)

1. ALL PARTS AND MATERIAL SHALL BE AS SPECIFIED OR APPROVED EQUAL QUALITY BY A PNNL REPRESENTATIVE.
2. AS-BUILT CONSTRUCTION SHALL BE MARKED ON DRAWING IF DIFFERENT THAN SHOWN.
3. ABBREVIATIONS ARE IN ACCORDANCE WITH ASME Y1.1-1989.
4. DIMENSIONING AND TOLERANCING ARE PER ASME Y14.5M-1994.
5. ALL DIMENSIONS ARE IN INCHES.

TOLERANCES: DECIMAL .X +/- .1
.XX +/- .01
.XXX +/- .005

ABBREVIATIONS

PMP PULSATING MIXER PUMP

TRI TANK RISER INTERFACE

DRAWING NO	DRAWING TITLE
H-3-308923	PMP CRADLE ASSY
H-3-308922	PMP DECON SPARY RING ASSY
H-3-308921	PMP FRAME ASSY

REFERENCE DRAWINGS

NEXT USED ON

PR	MF	QA BY / DATE	ENGR BY / DATE	CHK BY / DATE	REV BY / DATE	DESCRIPTION	REV NO

REVISIONS

CADCODE 3D:IBM:ACD2:14.0:SS CADFILE H-3-308920-1

EDP # 5435377-EDP01

DRAWN KS KOSCHIK	DATE 9/5/00
CHECKED DJ YEAGER	
OPTG APVD SD BURNETT	
ENGR BRIAN HATCHELL BK HATCHELL	
APVD MICHAEL W RINKER	
OTHER	
QA BARRY SACHS	

APPROVED FOR IMPLEMENTATION BY BRIAN HATCHELL FOR PNNL DATE 9/19/00

U. S. DEPARTMENT OF ENERGY
RICHLAND OPERATIONS OFFICE

PACIFIC NORTHWEST NATIONAL LABORATORY
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PULSATING MIXER PUMP ASSEMBLY

PROJ TITLE ORNL PULSATING MIXER PUMP SYSTEM

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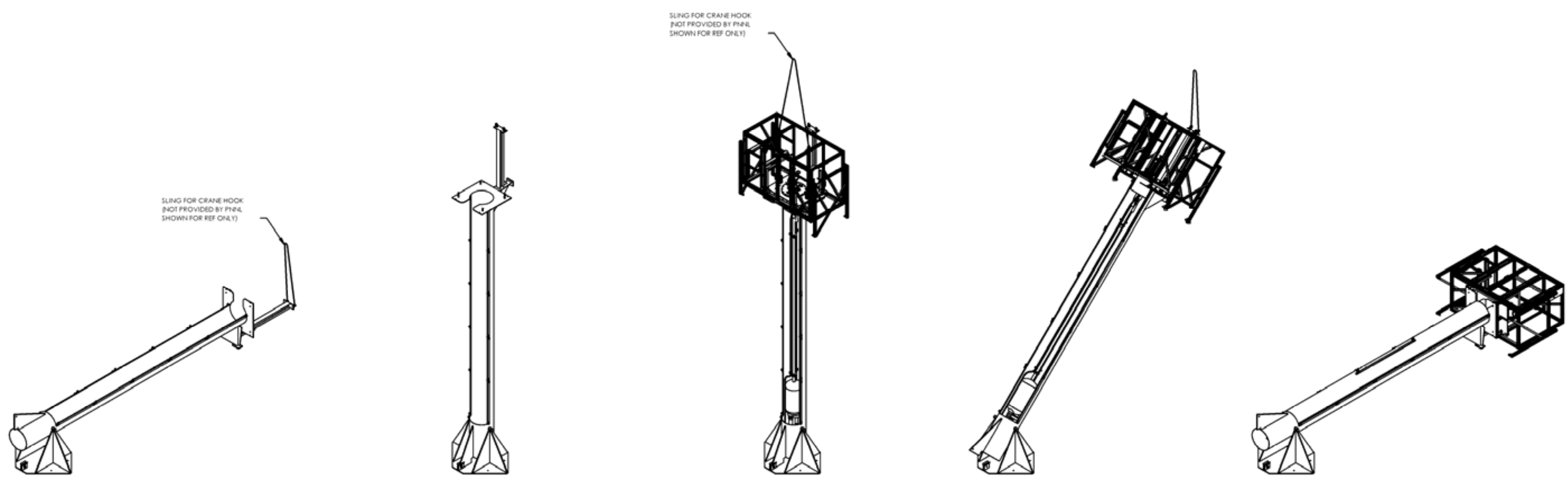
SCALE 1/2" = 1'-0" SHEET 1 OF 2



DEPLOYMENT SEQUENCE - 1
CRADLE IN
HORIZONTAL ORIENTATION

DEPLOYMENT SEQUENCE - 2
CRADLE IN
VERTICAL ORIENTATION

DEPLOYMENT SEQUENCE - 3
CRADLE IN
VERTICAL ORIENTATION
WITH PMP & TRI LOADED

DEPLOYMENT SEQUENCE - 4
CRADLE WITH
PMP & TRI BEING LOWERED TO
THE HORIZONTAL ORIENTATION

DEPLOYMENT SEQUENCE - 5
CRADLE WITH
PMP & TRI IN THE STOWED
POSITION WITH COVER ON

EDP # 5435377-EDP01

DRAWN KS KOSCHIK DATE 9/5/00
CHECKED DJ YEAGER
DPTG APVD SD BURNETT
ENGR BRIAN HATCHELL
BK HATCHELL
APVD MICHAEL W RINKER
OTHER
QA BARRY SACHS
APPROVED FOR IMPLEMENTATION
BY BRIAN HATCHELL
FOR PNNL DATE 9/19/00

U. S. DEPARTMENT OF ENERGY
RICHLAND OPERATIONS OFFICE
PACIFIC NORTHWEST NATIONAL LABORATORY
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PULSATING
MIXER PUMP
DEPLOYMENT SEQUENCE

PROJ TITLE ORNL PULSATING MIXER PUMP SYSTEM

SIZE F INDEX NO 2600 BLDG NO 77A DWG NO H-3-308920 REV NO 0
SCALE 1/4" = 1'-0" SHEET 2 OF 2

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